# Plankton Patch Feasibility Experiments

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## LONG -TERM GOALS

My long - term goal is to increase our understanding of the biological - biological, physical - biological and chemical - biological interactions that control the initiation, maintenance and dissipation of plankton patches. This goal can most readily be achieved by directly measuring processes thought to control plankton patch dynamics, experimentally testing their importance, incorporating those processes into conceptual plankton dynamics models, and then testing the models in the ocean.

## OBJECTIVES

My short-term objective is to increase our understanding of the mechanisms controlling the dynamics of thin layers. Thin layers are plankton patches that range in thickness from a few tens of centimeters to a few meters, yet can extend horizontally for kilometers and persist for more than 24 hours. In some cases thin layers can be sufficiently intense to affect biological rate processes and the performance of current and planned Navy optical and acoustical sensors. Although recent advances in optical and acoustic sensors have provided increasing evidence that thin layers can occur in a variety of stratified coastal systems, we are just beginning to sample their temporal and spatial extent and the mechanisms that control their dynamics. Our conceptual models based on a combination of tow tank experiments and preliminary field measurements have suggested that thin layer dynamics should be particularly sensitive to interactions with current shear and consumption by higher trophic levels (Donaghay and Osborn, 1997, Donaghay and Holliday, 1998). As a result, our objectives during the ONR Thin Layers Experiment were to (1) quantify the temporal and spatial scales of thin layers of phytoplankton and zooplankton, (2) test our model of the effects of episodic increases in current shear on thin layer formation, maintenance and dissipation, (3) test the hypothesis that zooplankton aggregate into thin phytoplankton layers, and (4) provide a broader scale context for the structure and process measurements made by the other members of the thin layers group.

## APPROACH

Our approach has been to complete papers on earlier work while continuing the numerical analysis of the unique set of fine scale profiles collected during the 1998 ONR Thin Layers Experiment conducted in East Sound, WA. During this experiment, a combination of basin scale transects and a triangular array of autonomous bottom-up profilers were used to simultaneously quantify currents and the vertical physical, biological, chemical, and optical structure over the wide range of temporal and spatial scales needed to test our models (Donaghay and Holliday, 1998). At the site of the array, we used our newly developed underwater winch CTD/optics profilers to collect more than 2 weeks of

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hourly finescale profiles of temperature, salinity, density, oxygen, spectral absorption and spectral transmission. These profiles were collected in close proximity to acoustic profiles of zooplankton collected at one minute intervals by Van Holliday and profiles of currents collected every 15 minutes by a bottom mounted ADCP.

## WORK COMPLETED

We have completed our work with Twardowski on quantifying the effect of photobleaching on spectral signature of CDOM using the 1996 and 1997 East Sound data. This paper has been accepted for publication in the Journal of Geophysical Research – Oceans (Twardowski and Donaghay, accepted).

We have completed our work with Alldredge on the occurrence and mechanisms of formation of a dramatic thin layer of marine snow during our 1996 East Sound cruise. The resulting paper has been accepted for publication in Marine Ecology Progress Series (Alldredge, Cowles, MacIntyre, Rines, Donaghay, Greenlaw, Holliday, Dekshenieks, Sullivan, and Zaneveld, accepted).

Jim Sullivan has completed his work on the effects of small-scale turbulence on the growth, mortality, bioluminescence and distribution of marine dinoflagellates. A paper combining lab experiments with field data from the 1998 East Sound summer experiment has been accepted for publication in J. Phycology (Sullivan, Swift, Rines and Donaghay).

We completed the calibration, numerical processing, and visualization of the optical and CTD data collected by the underwater winch profilers during the June 1998 East Sound experiment. We have plotted vertical profiles of absorption, attenuation, temperature, salinity and density for each of the more than 500 casts collected by the profilers. We have examined these finescale attenuation and absorption profiles to identify the thickness, intensity, persistence and temporal coherence of all sub-5 meter thick peaks that are observed in 2 or more profiles at one location. We have plotted the depth and location of these layers during the experiment to identify temporal and spatial patterns of occurrence of thin phytoplankon layers. We have used these data in combination with the CTD and current meter data to quantify the association of these thin layers with physical structure (temperature, salinity, density, current velocity), physical gradients (density gradients and current shear) and with estimates of the mixing environment (Richardson number). The resulting data has been combined into a master data file that has been shared with Holliday's group.

We have completed the numerical processing and visualization of the Tracor Acoustic Profiling System (TAPS) data collected by Van Holliday's group at 3 locations in the array. We have worked very closely with Holliday's group in this effort. We surface-referenced the TAPS data and made time series plots for backscatter intensity at each frequency for each location. We then used these plots to extract the depth and temporal location of all thin zooplankton layers evident in the backscatter data. Thin layers were defined as peaks in backscatter intensity at one or more frequencies that persisted for more than 2 hours. We have plotted the depth and location of these acoustic layers during the experiment to identify temporal and spatial patterns of occurrence of thin zooplankon layers. We have used these data in combination with the CTD and current meter data to quantify the association of these thin layers with physical structure (temperature, salinity, density, current velocity), physical gradients (density gradients and current shear) and with estimates of the mixing environment (Richardson number). The resulting data has been combined into a master data file that has been shared with Holliday's group. After discussing these results with Holliday's group at a meeting in San Diego, we used their programs to convert the backscattering data to estimates of biovolume. We then made time series plots of the vertical structure of zooplankton biovolume for each location and used

these plots to extract the intensity, depth and temporal location of all thin zooplankton layers evident in the biovolume data from each of the TAPS sites. We have plotted the depth and location of these layers during the experiment to identify temporal and spatial patterns of occurrence of thin layers of zooplankton biovolume. We have used these data in combination with the CTD and current meter data to quantify the association of these thin zooplankton biovolume layers with optical layers (attenuation and absorption), physical structure (temperature, salinity, density, current velocity), physical gradients (density gradients and current shear) and with estimates of the mixing environment (Richardson number). We have created plots and master files of these results and exchanged them with Holliday's group. Finally, we have examined the size composition of the zooplankton inside and outside all thin layers seen in the biovolume data.

**RESULTS**

Our ongoing analysis of the centimeter-scale physical, optical, and acoustic profiles has provided important insights into the temporal and spatial scales of thin layers and the mechanisms that control their dynamics.

First, analysis of the 2 weeks of fine scale optical and acoustic data collected at the array indicates that plankton layers can be far thinner and far more coherent than previously thought. For example, optical layers as thin as 12 cm can persist for more than 18 hours and extend for kilometers. Analysis of the acoustic data has shown that sub-meter-scale thin zooplankton layers are far more spatially coherent and persist far longer (days versus hours) than the multi-meter thick patches that have been extensively studied in the past. For example, while acoustic layers thicker than 3 meters rarely persisted for more than a few hours and were almost never detected by more than one TAPS, thin acoustic layers were frequently detected at all 3 TAPS locations over periods ranging from 6 hours to three days (Figure 1). Given average current velocities of 10 cm/sec and the 300 m spatial separation of the TAPS, this means these zooplankton layers had horizontal coherence scales of kilometers.

Second, analysis of the finescale phytoplankton, zooplankton and current velocity data indicates that while thin layers show remarkable spatial coherence, the depth at which they occur can vary dramatically over time (Figure 1). Although multiple explanations can be suggested based on the biological data alone, overlays of acoustic layer depth on density indicate that much (but not all) of this variability in depth is associated with temporal changes in density structure (Figure 1). This should not be surprising since the zooplankton that form these persistent thin layers do not appear to vertically migrate, but instead aggregate in the primary pycnocline or in weak density gradients elsewhere in the water column (Figure 1). An examination of the currents and current shear at the depth of these layers indicates that these zooplankton patches are episodically exposed to periods of high shear that will tend to spread them horizontally, make them thinner and tilt the layer relative to the pycnocline. These results are consistent with our model (Donaghay and Osborn, 1997, Donaghay and Holliday, 1998) that current shear and interactions between swimming behavior and vertical gradients tend to dominate thin layer dynamics and thus give them higher temporal and spatial coherence than thick layers that tend to be dominated by balances between growth and losses to predation and physical dispersion.

Third, analysis of finescale optical and acoustical profiles indicates that while there are periods when thin layers are temporally persistent and spatially coherent, there are also periods when they do not occur (Figure 1). Our statistical analysis of the optical data indicates that thin layers of phytoplankton can only develop and persist when the balance between local shear and buoyancy (e,g., Richardson number) is sufficient to suppress turbulent mixing (Dekshenieks, et al., in press). Our analysis of the zooplankton data indicate that while their enhanced swimming capabilities may allow them to form

and maintain thin layers over a broader range of mixing conditions, there are combinations of high winds, weak stratification and strong internal waves that can provide conditions that can prevent zooplankton from forming and maintaining thin layers (Figure 1).

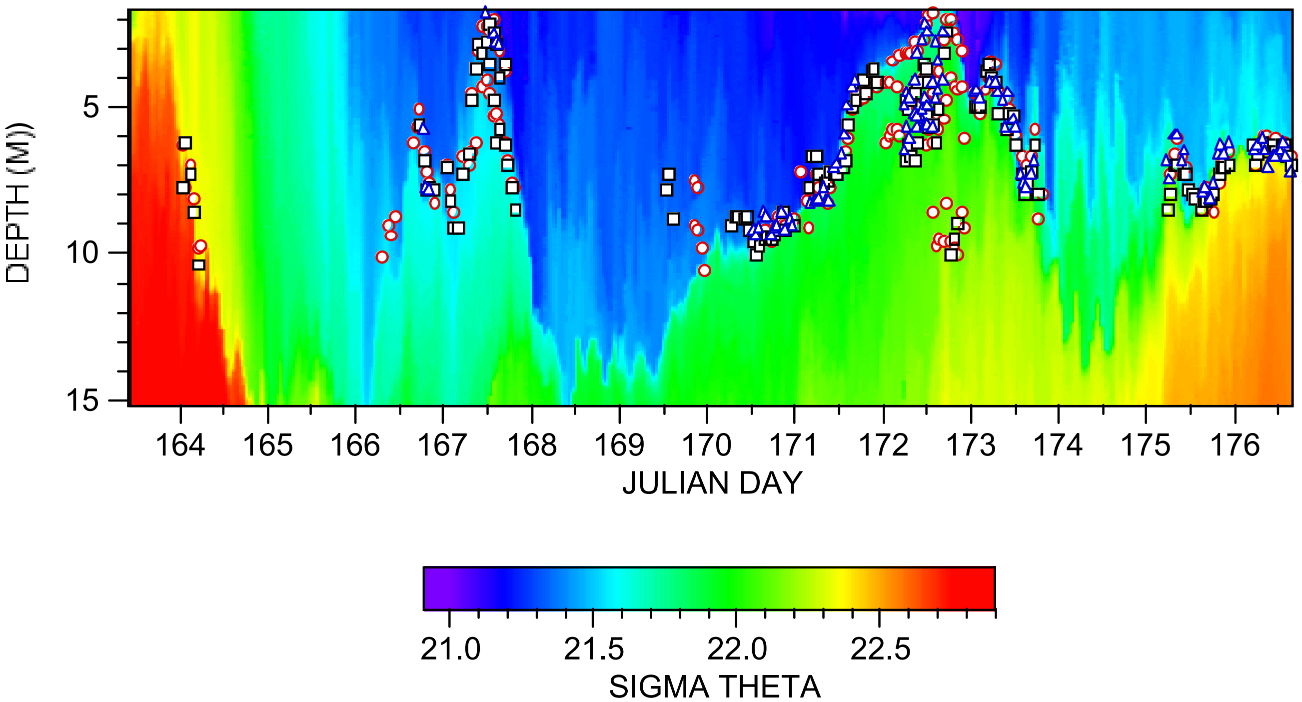


***Figure 1. Relationship between the density structure of the water column (color plot of sigma theta) and the occurrence of temporally persistent and spatially coherent thin layers of zooplankton indicated by peaks in acoustic backscattering at 420 kHz at each sampling location (symbols). Density data was collected with centimeter resolution once an hour with the bottom-up underwater winch profilers and the acoustic data was collected simultaneously at 3 locations 300m apart with temporal resolution of 1 second and vertical resolution of 12 cm. The acoustic data show that zooplankton formed spatially coherent layers at one or more depths on 4 occasions during the 2 week sampling period. These layers varied in depth over time, but persisted for periods of hours to several days. Changes in layer depth tended to follow changes in the depth of the pycnocline. There were also several multi-day periods of strong winds and weak density stratification during which no zooplankton layers were detected.***

Finally, analysis of finescale optical and acoustical profiles indicates that conventional multi-meter scale sampling can underestimate by orders of magnitude the concentrations of plankton that occur in thin layers and the steepness of gradients between layers and surrounding waters. This means that we have not only underestimated concentration- and gradient-dependent biological rate processes, but that we have also underestimated the impact of the high concentrations of thin plankton layers on the absorption and scattering of light and sound. This has serious implications for interpreting data from optical and acoustic sensors deployed in coastal waters.

## IMPACT

One of the central paradigms in biological oceanography has been that small scale mixing processes in the upper ocean are sufficiently strong and equal in all directions that sub-meter scale biological, chemical and optical structures will be rapidly dispersed and thus can be ignored in both sampling and modeling upper ocean dynamics. Our tow tank and field experiments clearly challenge the generality of this paradigm by demonstrating such features can persist for more than 24 hours and extend horizontally for kilometers. Our field results and theoretical analyses indicate that biological-physical, biological-chemical and biological-biological interactions occurring at these scales may control not only the development of blooms of toxic and/or bioluminescent phytoplankton, but also the extent to which zooplankton are able to exploit phytoplankton production. Equally importantly, our field observations indicate that the fine-scale biological layers can be sufficiently intense to alter optical and acoustical characteristics of these waters.

## TRANSITIONS

We have expanded our efforts to transition our research to the Navy and private industry. First, we have developed a National Ocean Partnership Program project designed to extend and transition our 4-D finescale profiler technology. Partners in this project are Alfred Hanson (SubChem Systems), Casey Moore and Ron Zaneveld (WET Labs), Alan Weidemann (NRL-Stennis), LCDR Kimberly Davis-Lunde (Commander, Naval Meteorology and Oceanography Command) and Richard Green (Environmental Protection Agency Gulf Ecology Laboratory). Second, we have continued to work with Navy scientists and engineers at NUWC (Newport) to transition our results.

## RELATED PROJECTS

1. I am continuing a long-term collaboration with Van Holliday (BAE Systems) in trying to quantify zooplankton thin layers and understand how those layers are related to phytoplankton fine structure and physical forcing. We have shared data and spent several weeks working with Holliday's group at his lab.

2. Margaret Dekshenieks (UCSC), Tom Osborn (Johns Hopkins) and I are trying to understand large scale physical forcing of thin layer dynamics.

3. I am working with Tim Cowles (OSU), Ron Zaneveld (OSU), Emanual Boss (OSU) and Margaret Dekshenieks (UCSC) to combine all the transect and bottom-up profiler data to assess the temporal and spatial extent and characteristics of thin optical layers measured during June 1998.

4. Jan Rines (URI) and I are working on the role of small-scale mixing processes in controlling the dynamics of non-spheroid diatoms. We are also working on a literature review and website summarizing the evidence for thin layers in marine waters.

5. Mary Jane Perry (UM), Tim Cowles (OSU) and I are working on a new method to estimate in situ growth rates of thin phytoplankton layers.

6. Alan Weidemann (NRL Stennis), Jan Rines (URI), Margaret Dekshenieks (URI) and I are working on fine scale phytoplankton and optical structure

## REFERENCES

Donaghay, P.L., and T.R. Osborn, 1997. Toward a theory of biological-physical control of harmful algal bloom dynamics and impacts. Limnol. Oceanogr., 42(5): 1283-1296.

Donaghay, P.L. and D. V. Holliday, 1998. Thin Layers Program Plan: Research at critical scales in the marine environment. Prepared for ONR Biological and Chemical Oceanography Program.

Dekshenieks, M. M., P.L. Donaghay, J. M. Sullivan, J.E.B. Rines, T. R. Osborn, and M.S. Twardowski, in press. Temporal and spatial occurrence of thin phytoplankton layers in relation to physical processes. Marine Ecology Progress Series.

## PUBLICATIONS

Twardowski, M. S., and P. L. Donaghay, 2001. Separating in situ and terrigenous sources of absorption by dissolved material in coastal waters. Journal of Geophysical Research – Oceans, 106 (C2): 2545-2560.

Dekshenieks, M. M., P.L. Donaghay, J. M. Sullivan, J.E.B. Rines, T. R. Osborn, and M.S. Twardowski, in press. Temporal and spatial occurrence of thin phytoplankton layers in relation to physical processes. Marine Ecology Progress Series.

Rines, J.E.B., P. L. Donaghay, M. M. Dekshenieks, and J. M. Sullivan, in press. Thin layers and camouflage: hidden *Pseudo-nitzschia* populations in a fjord in the San Juan Islands, Washngton, USA. Marine Ecology Progress Series.

Twardowski, M. S., and P. L. Donaghay, accepted. Solar photobleaching of the spectral absorption of chromatophoric dissolved organic materials in field data and lab incubations. Journal of Geophysical Research – Oceans.

Sullivan, J. M., E. Swift, J. E. B. Rines, and P. L. Donaghay, accepted. The functional relationships between small-scale turbulence and the growth and morphology of two species of marine dinoflagellates: *Lingulodinium polyedrum* and *Alexandrium catenella*. J. Phycology

Twardowski, M. S., and P. L. Donaghay, accepted. Solar photobleaching of the spectral absorption of chromatophoric dissolved organic materials in field data and lab incubations. Journal of Geophysical Research-Oceans.

Alice L. Alldredge, A.L., T.J. Cowles, S. MacIntyre, J. E.B. Rines, P. L. Donaghay, C.F. Greenlaw, D.V. Holliday, M.M. Dekshenieks, J.M. Sullivan, and J.R.V. Zaneveld, accepted. Occurrence and mechanisms of formation of a dramatic thin layer of marine snow in a shallow Pacific fjord". Marine Ecology Progress Series.

## PATENTS

None.